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Comparative studies of MSGC and GEM for photon and electron detection at ambient conditions

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ABSTRACT

Experimental work relevant to the electron and photon detection in X-ray Absorption Spectroscopy (XAS) experiments is described using a Micro-Strip Gas Chamber (MSGC) and a Gas Electron Multiplier (GEM) operated at atmospheric pressure. XAS studies at ambient conditions dictate the use of predominately Helium counter gas mixture with minimal quench gas concentration whilst attaining charge gains in the 10^4 region. We present results on the charge gain for both MSGC and GEM detectors using He/iso-C₄H₁₀ based gas mixtures. Pulse-height distributions due to the Total Electron Yield (TEY) arising from interactions between 8.05 keV X-rays and Titanium sample, i.e. photoelectrons, auger electrons and fluorescent photons, are also presented. Employing a repelling voltage grid close to the sample surface permitted the separation of TEY and the Fluorescent Yield (FY) signal.

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1. Introduction

Introduced by Oed [1] the Micro-Strip Gas Counter (MSGC) is realised on a plate of some suitable semi-insulating material using microlithography techniques. Fine anode strips (typically 10 μ m wide) are interleaved with cathode strips (typically >100 μ m wide) in a repetitive pattern which has a pitch of several hundred microns. When a voltage of about ≈ 500 V is established between anode and cathode strips in a suitable gas atmosphere the free electrons deposited in the gas experience amplification near the anode strips. These signals can be detected on individual anodes or on areas of bussed anode strips.

The gas electron multiplier (GEM) was invented at CERN in 1997 [2] and consists of a thin polymer mesh (50 μ m thick Kapton), metal clad on both sides usually by 5 μ m thick copper and perforated with a high density of holes (typically 40–120 μ m hole diameter, 140–200 μ m hole pitch). Upon the application of a potential difference across the GEM holes in a suitable counter gas mixture, charge amplification is achieved when electrons enter the GEM holes.

Conventional X-ray Absorption Spectroscopy (XAS) uses ionisation chambers to monitor signal attenuation by a sample as a

function of the photon energy. The absence of the charge gain in ionisation chambers renders the conventional XAS studies rather disadvantageous for applications where the sample contains low atomic species (Carbon, Nitrogen, Oxygen, etc.) or when studying the transition metal oxides involving LM transitions for which a detector response in the 270–1000 eV X-ray energy region is required. To improve the conventional XAS at lower X-ray energies requires the introduction of proportional counters [3,4]. In the present study, we have used a MSGC and a GEM to study the pulse-height distributions resulting from the emissions caused by de-excitations of a Titanium sample excited by a laboratory based X-ray source (8.05 keV Cu-K X-rays). For XAS experiments utilising the gaseous detector technology, it becomes necessary to use predominately Helium in the counter gas mixtures. This allows the passage of the primary incoming beam to interact with the sample atoms without distorting the output signal due to interactions with the counter gas and by other side minimises the pulse-height spectra distortion due to the re-absorption of primary electrons deposited by the fluorescent photons of low energy in the gas medium close to the sample/drift-electrode.

In order to accomplish sub-keV X-rays detection, the detector must achieve a charge gain of $\sim 10^4$ with the Helium based gas mixtures. In the present studies, the charge gain characteristics of a MSGC were examined as a function of its anode-cathode voltage using He/iso-C₄H₁₀ (75/25%) and He/iso-C₄H₁₀ (85/15%) whilst similar work was carried out to establish the charge gain

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characteristics of a GEM as a function of voltage applied across the GEM holes for a number of different He/iso-C₄H₁₀ gas mixtures.

Total Electron Yield (TEY) XAS technique combined with gaseous detectors offers the possibility of investigating the surfaces at ambient conditions [5–8]. The TEY method is particularly suited for obtaining quantitative information about the local atomic structure of diluted atomic species in solids as well as liquids. The interaction of a synchrotron beam with a given sample, usually at glancing angles, produces photoelectrons, auger electrons and fluorescent photons. The primary charge signal is amplified by the gaseous detector thereby improving the signal-to-noise ratio. In order to examine the X-ray absorption coefficient around the constituent K, L or M absorption edges, the energy of the incoming photon is varied using a monochromator.

Whilst TEY is a surface phenomena, typically 10–100 nm, the fluorescent photons produced by the incoming X-ray beam emerge from the bulk (several microns deep) of the material being examined. These are usually absorbed within the active volume of the gaseous detector and constitute the Fluorescent Yield (FY) signal. In order to study TEY and FY independently requires a repelling voltage grid in the proximity of the sample [9]. By biasing the repelling grid negative with respect to the sample surface, the signal due to the photoelectron and auger electrons (TEY) is almost entirely blocked permitting only the fluorescent events (FY) to be recorded. In the present studies we will demonstrate the potential of this concept using a Titanium sample.

2. Experimental setup and methodology

The experimental arrangement for measuring the pulse-height distributions and charge gains of the MSGC and GEM is shown in Fig. 1, noting that either a MSGC or a GEM was used at any given time. The MSGC plate was manufactured by Baumer IMT, Greifensee, Switzerland using the semiconducting S8900 glass. The electrode geometry was based on a previous high charge gain structure albeit using argon based counter gas mixtures [10], and consisted of 300 μ m wide cathodes and 5 μ m anodes set at

500 μ m pitch. The active area of the device was approximately $20 \times 10 \text{ mm}^2$.

The GEM was fabricated at the CERN TS-DEM workshop and consisted of a 50 μ m thick copper clad (5 μ m thickness) Kapton foil with 70 (50) μ m diameter holes in copper (Kapton) patterned at 140 μ m hole pitch. The GEM used here had an active area of $50 \times 50 \text{ mm}^2$ and was supported on a G-10 frame. The gap between the GEM and the readout plane is known as the induction gap and was set at 1 mm whilst the drift gap (distance between sample and GEM or MSGC) was set at 10 mm.

The first part of the present work was to determine the charge gain characteristics of the MSGC and the GEM. This was done using a Fe-55 (Mn-K X-ray (5.89 keV)) beam which illuminated the detector drift space perpendicular to the MSGC or the GEM planes. In this study, the detection chamber was operated at a constant gas flow rate where the gas composition was controlled by Brooks mass-flow controllers (model 5850E) built into a rig that was constructed using stainless steel tubing. The count rates used throughout these studies were kept in the region of 10 kHz.

For the case of MSGC, the variation of charge gain was investigated as a function of the potential difference V_{ac} across the MSGC anode and cathode strips. Charge gain characteristics were obtained using He/iso-C₄H₁₀ gas mixtures with concentrations of 75/25% and 85/15%. The drift electrode was operated at negative potential ($V_d = -1500 \text{ V}$) with respect to the MSGC anodes that were held either close to ground. The MSGC anode-strips were connected to an Ortec preamplifier (model 142A). The preamplifier output is then fed into an Ortec shaping amplifier (model 575A) with shaping time constants adjusted to 0.5 μ s. Bipolar output of the shaping amplifier in turn fed an Ortec pulse-height analyser (Ortec ASPEC-927).

The charge gain characteristics of the GEM were also investigated as a function of the voltage applied across the GEM holes, ΔV_{GEM} , whilst the induction field was set at 6 kV/cm. Four different concentrations of iso-C₄H₁₀ (5, 15, 20 and 25%) in Helium were used. In each set of measurements, ΔV_{GEM} was gradually increased up to the onset of micro-discharges. In order to protect the GEM from current surges, we used a twin high-voltage tracking power-supply (Iseg, NHQ 224L_503_K04) which allowed the voltages at both sides of the GEM to be ramped up simultaneously by the first channel when setting the induction field and then increasing voltage at the top side of the GEM using the second channel. The trip limit was set to 0.5 μ A currents, beyond which the power supplies were automatically turned off.

The charge gain for each V_{ac} or ΔV_{GEM} used was obtained by comparing the peak of the pulse-height distribution produced by the Fe-55 radioactive source and then calibrating the pulse-height spectrum with an accurately known charge. This was done in the usual way of by supplying a known step voltage into the preamplifier test input capacitance. By dividing the peak charge with the number of primary electrons produced in the conversion/drift region of the detector yielded the effective charge gain for a given bias settings. For example, in the case of He/iso-C₄H₁₀ (85/15%) the primary charge $n_0 \approx 154$ electron-ion pairs, taking into account an average energy $w \approx 38.3 \text{ eV}$ [11,12] to produce an electron-ion pair in this gas mixture.

In order to study TEY and FY independently, a repelling grid comprising of 50 μ m diameter nickel wires at 0.5 mm pitch and running in a direction parallel to the X-ray beam. This grid was held at approximately 2 mm from the drift (Titanium plate) electrode. A collimated X-ray generator beam (8.05 keV Cu-K X-rays) was used to excite the Titanium sample at grazing incidence. For a given counter gas mixture and for voltages V_{ac} or ΔV_{GEM} , pulse-height distributions were recorded as a function of the repelling grid voltage, V_g , whilst the drift voltage was held at $V_d = -1500 \text{ V}$.

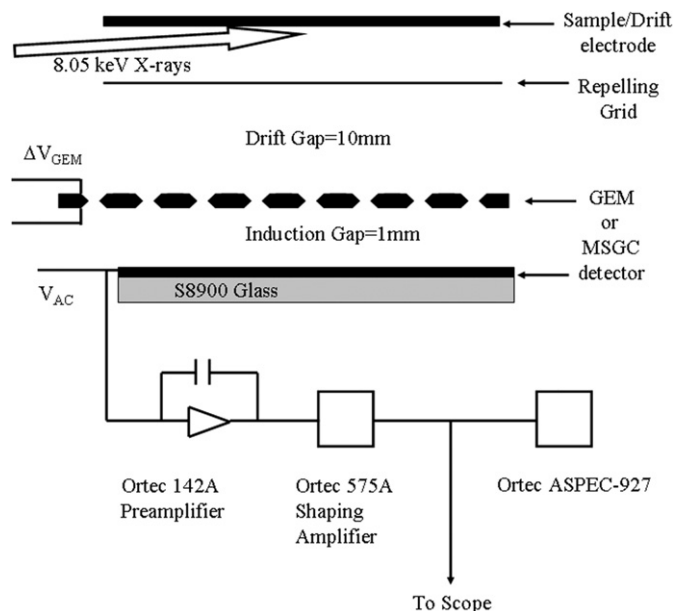


Fig. 1. Schematic arrangement showing the MSGC and the GEM detector.

3. Experimental results and discussion

Fig. 2 shows the variation of the charge gain versus the anode-cathode voltage, V_{ac} , for the present MSGC using He/iso- C_4H_{10} gas mixtures of 75/25% and 85/15%. The maximum charge gains before the onset of electrical instabilities are approximately 2×10^4 and 6×10^3 for He/iso- C_4H_{10} of 75/25% and 85/15%, respectively, showing the importance of the quench gas concentration to achieve higher gains. We note that upper charge gains are much lower than those obtained using argon based gas mixture for similar (optimised) MSGCs [10]. Fig. 3 shows the variation of the charge gain versus the voltage applied across the GEM holes, ΔV_{GEM} , for several He/iso- C_4H_{10} gas mixtures of 95/5%, 85/15%, 80/20% and 75/25%. The induction field during these measurements was set at 6 kV/cm. Fig. 3 demonstrates that the present GEM based detector can achieve charge gain exceeding 5×10^4 thus easily permitting studies in the sub-keV X-ray region. The high charge gain properties of the GEM, at relatively small concentration of the quench gas, are attributed to electron multiplication occurring within the GEM holes, and consequently the avalanche confinement allows a lower photon feedback [13]

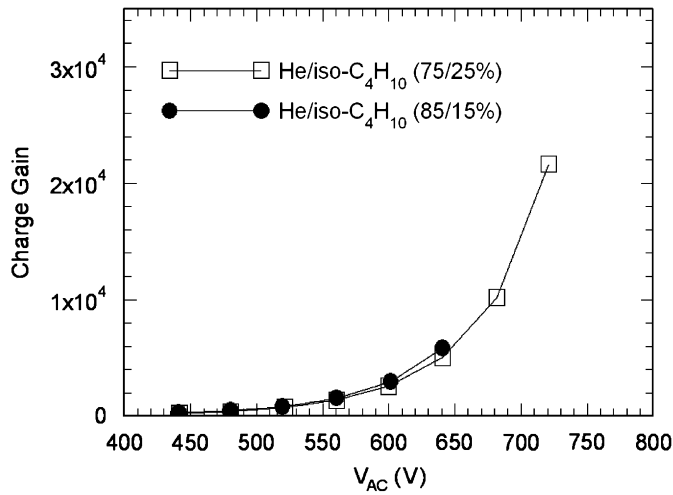


Fig. 2. Charge gain of the MSGC as a function of the anode-cathode voltage, V_{ac} , using He/iso- C_4H_{10} gas mixtures of 75/25% and 85/15%.

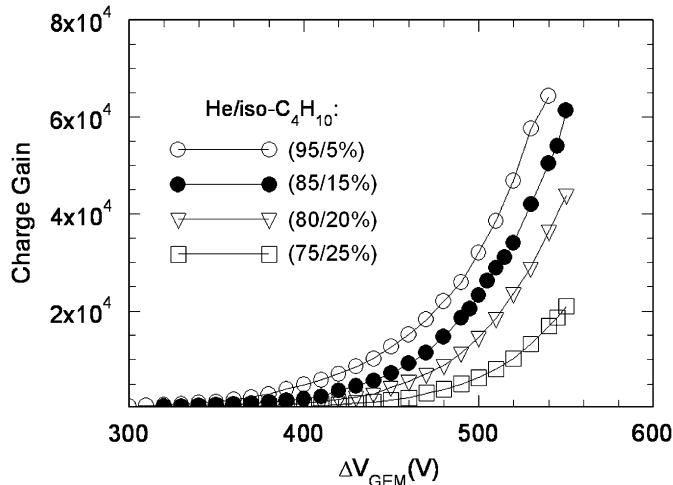


Fig. 3. Charge gain of the GEM as a function of the voltage applied across the GEM holes, ΔV_{GEM} , using He/iso- C_4H_{10} gas mixtures of 95/5%, 85/15%, 80/20% and 75/25%.

and improved detector stability is observed at relatively high gains than planar devices such as MSGCs [14,15].

Fig. 4 shows the pulse-height distributions due to TEY and FY signals using the MSGC detector. These signals are attributed to emissions from the Titanium sample originally induced by 8.05 keV photons. The MSGC in this instance was operated in He/iso- C_4H_{10} (75/25%) at a charge gain of approximately 2×10^3 . By increasing the repelling grid voltage beyond the sample voltage, it is clear that TEY signals are almost entirely cancelled. For the case shown in Fig. 4 where the sample was held at $V_d = -1500$ V, holding the repelling grid at $V_g = -1600$ V was sufficient for this purpose. At that point, the pulse-height distributions, corresponded to the Titanium K_{α} fluorescent photons at 4.51 keV (FY), are evident, which are shown in more detail in Fig. 5.

Since the GEM detector demonstrated much higher charge gains than the MSGC, it was possible to obtain TEY and FY signals at much higher gains whilst using a smaller percentage of iso- C_4H_{10} quench gas in Helium. Fig. 6 shows pulse height-distributions due to the TEY and FY signals (Titanium sample with 8.05 keV incoming photons) using the GEM detector with He/iso- C_4H_{10}

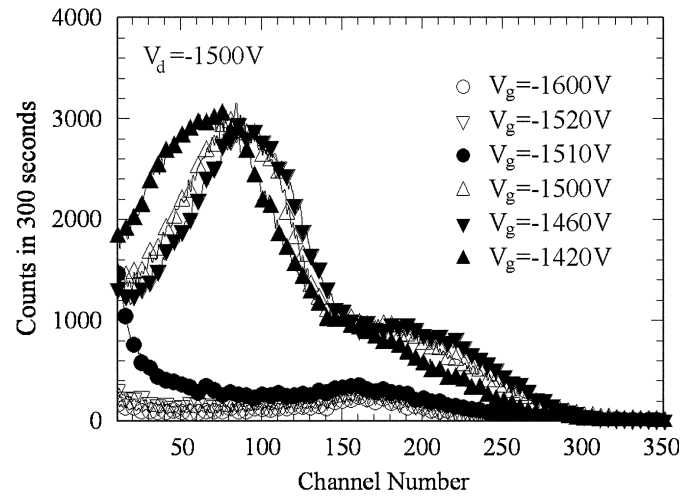


Fig. 4. Pulse-height distributions using the MSGC operated at a charge gain of 2×10^3 with He/iso- C_4H_{10} (75/25%). The Titanium target was held at $V_d = -1500$ V and excited with 8.05 keV X-rays. The upper curves represent TEY and FY signals when the repelling voltage $V_g \geq -1500$ V. The lower curves are due to FY signals when $V_g < -1500$ V.

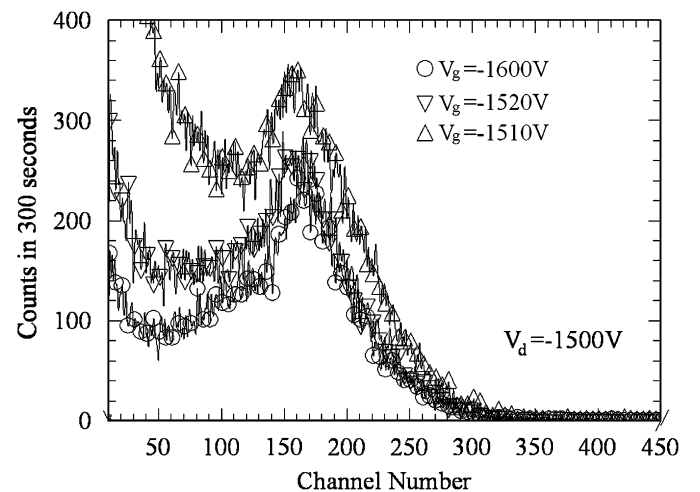


Fig. 5. Detail of pulse-height distributions depicted in Fig. 4, showing only the Titanium K_{α} fluorescent photons at 4.51 keV (FY).

(85/15%) when the charge gain was held at 2.8×10^4 . The TEY signals were once again eliminated the repelling grid, by a few tens of volts. One of the attractive feature demonstrated by the GEM detector was the superior energy resolution of the FY signals as shown in Fig. 7 (Titanium K_α at 4.51 keV) when compared with FY signals obtained using a MSGC (see Fig. 5).

Fig. 8 shows the FY signals using the GEM detector with the Titanium sample and 8.05 keV incoming photons. Here the gas mixture He/iso-C₄H₁₀ (95/5%) was used operating at a gain of approximately 3.2×10^4 . The degradation of the X-ray energy resolution is caused by the cumulative effects such as photon feedback, boundary effects and X-ray interactions at the detector chamber walls. The intensity of the photon feedback processes increases with a reducing quench gas concentration due to an increased transparency of spurious UV photons. These photons have sufficient energy to liberate single electrons at, for example, the drift electrodes. The secondary signal is usually very fast and for the present 0.5 μ s shaping amplifier time constant, adds to the primary signal thus giving rise to a pulse height spectrum with a pronounced high energy tail [16,17] as well as a typical exponential tail associated with single electron UV response. The attenuation length of the fluorescence photons also becomes

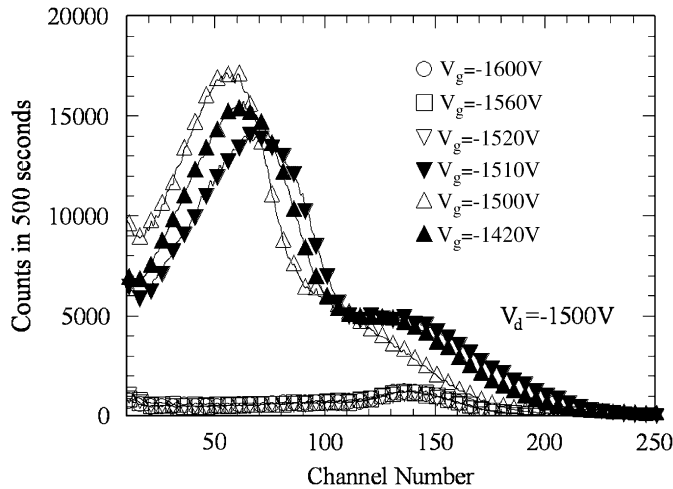


Fig. 6. Pulse-height distributions using the GEM operated at a charge gain of 2.8×10^4 with He/iso-C₄H₁₀ (85/15%). The Titanium sample was held at $V_d = -1500$ V and excited with 8.05 keV X-rays. The upper curves represent TEY and FY signals whilst the lower ones are those corresponding to FY signals.

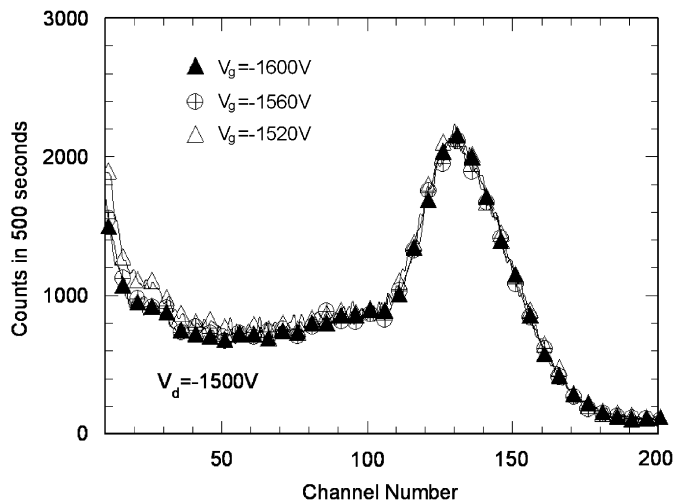


Fig. 7. Detail of pulse-height distributions depicted in Fig. 6, showing only the Titanium K_α fluorescent photons at 4.51 keV (FY).

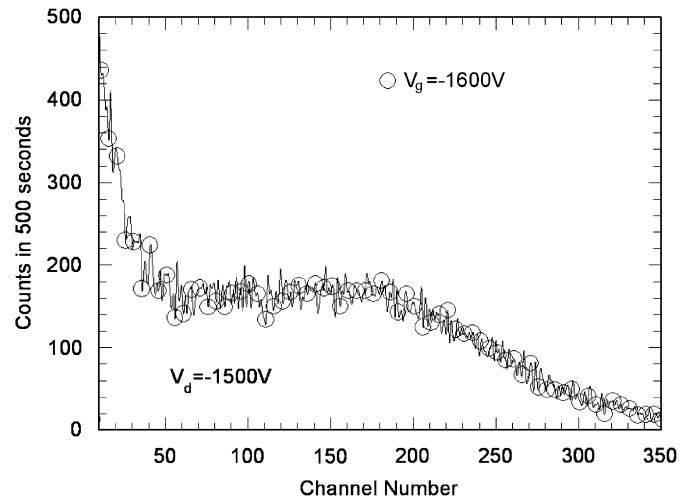


Fig. 8. Pulse-height distributions using the GEM operated at a charge gain of 3.2×10^4 with He/iso-C₄H₁₀ (95/5%).

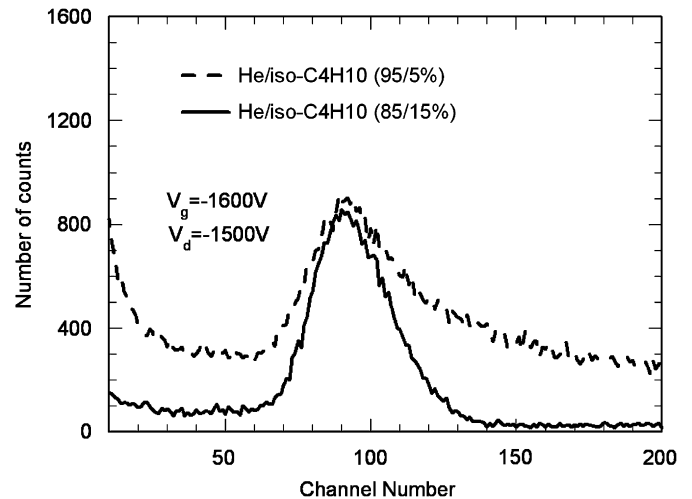


Fig. 9. Pulse-height distributions of the Aluminium K_α fluorescence (1.49 keV) photons. The GEM was operated at a charge gain of 2.4×10^4 for both He/iso-C₄H₁₀ gas mixtures of 95/5% and 85/15%. The electronic gain for these distributions was doubled in relation to the distributions shown in Figs. 7–8.

large with decreasing concentration of the quench gas leading to the detection of partial events at the detector boundaries.

The degradation of the X-ray energy resolution with lower quench gas concentration was cross-checked by observing pulse height distributions due to the fluorescence from an Aluminium target (1.49 keV) using He/iso-C₄H₁₀ gas mixtures of 85/15% and 95/5%, both operated at a charge gain of 2.4×10^4 . Whilst near optimum X-ray energy resolution was observed when using the He/iso-C₄H₁₀ (85/15%) mixture ($\sim 33\%$ FWHM), much poorer pulse-height spectrum was obtained with the He/iso-C₄H₁₀ (95/5%), as depicted in Fig. 9, where the appearance of events above the 1.49 keV peak, as well as the low energy tail begin to dominate. We should note that the electronic chain gain associated with Fig. 9 was doubled when compared with that used to obtain Figs. 7–8.

4. Summary and future work

We have demonstrated that GEM detectors deliver much higher charge gain, at least by an order of magnitude, for He/iso-C₄H₁₀ gas

mixtures with small quench gas concentration when compared to a MSGC device. This is in converse to the charge gain characteristics of the MSGC in Ar/iso-C₄H₁₀ gas mixtures. However, when using the MSGC with He/iso-C₄H₁₀ mixtures, it becomes more prone to the photon feedback effects due to greater transparency of the spurious UV photons and its planar geometry. In contrast, the GEM inherently suppresses the UV photons due to electron avalanche processes taking place within its holes and allows operation in high charge gain regime with reduced quencher concentration. The superior charge gain properties of the GEM detectors makes them potentially useful for XAS experiment at synchrotron beam lines when investigating, for example, transition metals alloys. We have also shown the benefits of using a simple repelling voltage grid to separate the FY signals from the TEY signals.

Further work is in progress to improve the work described in this paper. In particular, the Nickel grid will be substituted by graphite fibres to avoid signal contamination via the TEY and the FY signals associated with Nickel LM transitions. The photon feedback effects lead to instabilities and degradation of the X-ray energy resolution in gaseous detectors and the intensity of these processes increases with increasing charge gains and decreasing quench gas concentration. By utilising a two stage amplification device in the future work, such as a GEM-MIGAS [18–20], higher charge gains are expected with lower iso-C₄H₁₀ concentrations ($\leq 5\%$) whilst preserving the X-ray energy resolution of the fluorescent photons.

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